EVIDENCE FOR THE ISOSCALAR GIANT DIPOLE RESONANCE IN ^{208}Pb

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As described in the 1993 IUCF Annual Report,[1] we have undertaken a detailed investigation of the Isoscalar Giant Dipole Resonance (ISGDR), also referred to as the "squeezing mode" and best described as a "hydrodynamical density oscillation" in which the volume of the nucleus remains unchanged and the energy of the state is in the form of a compression wave oscillating back and forth through the nucleus.[2] This is a second order effect (in the first order, the isoscalar dipole mode corresponds to a spurious center of mass motion) and, in addition to being of substantial intrinsic interest as an exotic mode of collective oscillation, is of considerable interest because, like the monopole resonance (or "breathing mode"), it provides a direct measure of nuclear incompressibility.[3] Thus a detailed and systematic investigation of the ISGDR would provide additional information leading to a more precise determination of the incompressibility of infinite nuclear matter.

Our measurements employed a 200 MeV α beam incident on an enriched 3.0 mg/cm^2 thick ^{208}Pb target. Inelastically scattered α particles were detected in the focal plane of the K600 magnetic spectrometer operating in the transmission (0°) mode;[4] the available excitation-energy bite in this mode was 14-29 MeV, appropriate for the aforementioned resonances which are expected to lie at excitation energies of 20-22 MeV in ^{208}Pb. Our ray-tracing technique yielded an angular resolution of 2.1 mrad in the vertical and 3.0 mrad in the horizontal directions. Fig. 1 shows projections of a "multi-slit" aperture in the horizontal and vertical directions. A ^{24}Mg target was used to provide our energy calibration. The energy resolution of our measurements was approximately 130 keV; although the K600 is capable of a much better energy resolution, we chose not to divert a great deal of beam time to optimal dispersion matching since this resolution was more than adequate for measuring the ISGDR.

The measurements at small angles, as is well known, require a very careful tuning of the beam to minimize the contributions from the background due to beam halo and slit scattering, etc. After considerable effort, it was possible to obtain a rather "clean" beam

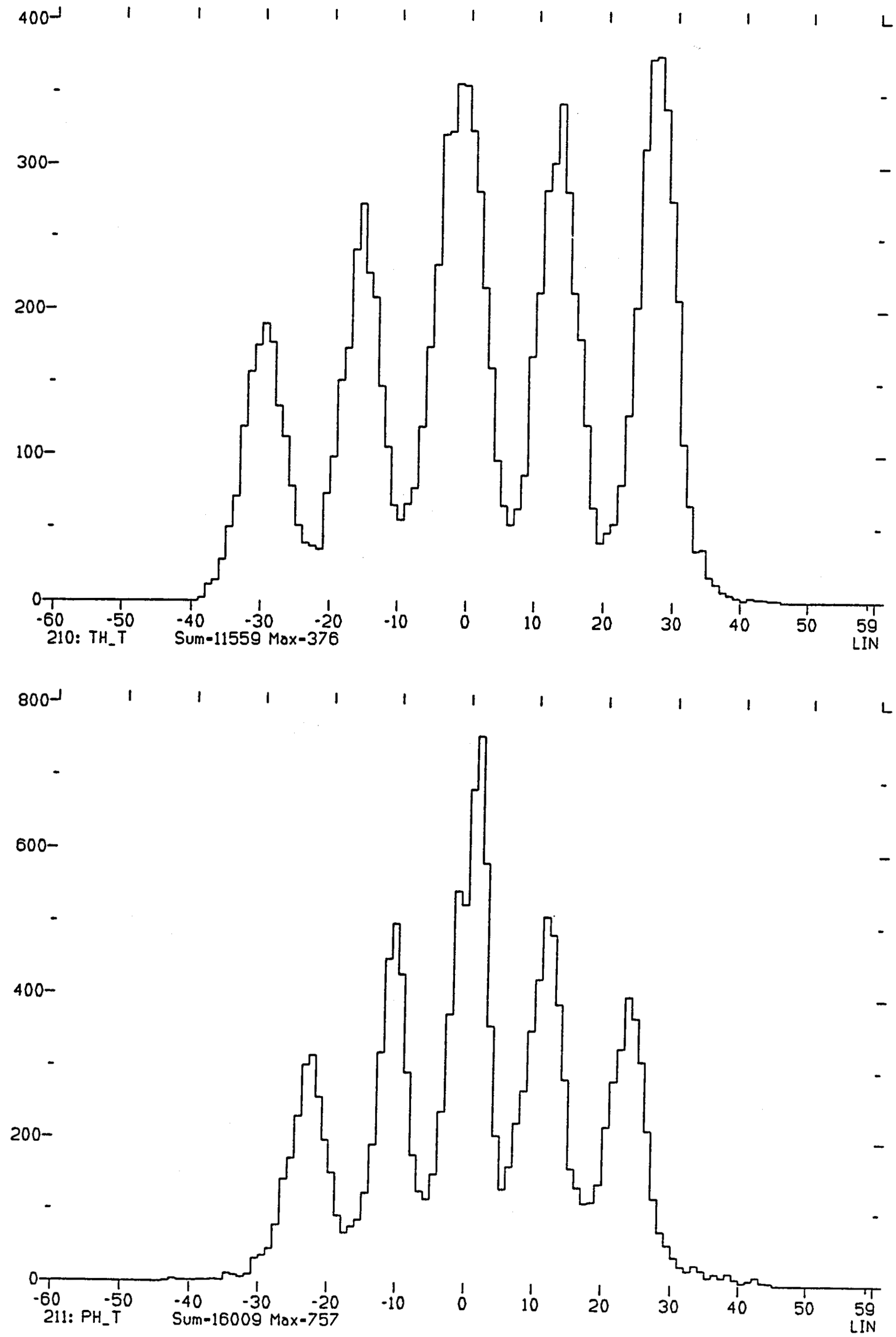

Figure 1. Calibration spectra for horizontal (TH_T) and vertical (PH_T) angle measurements using an entrance aperture with five slits separated by 14.5 mrad. The slit widths are 4.5 mrad except for the center slit which is 6.8 mrad wide.

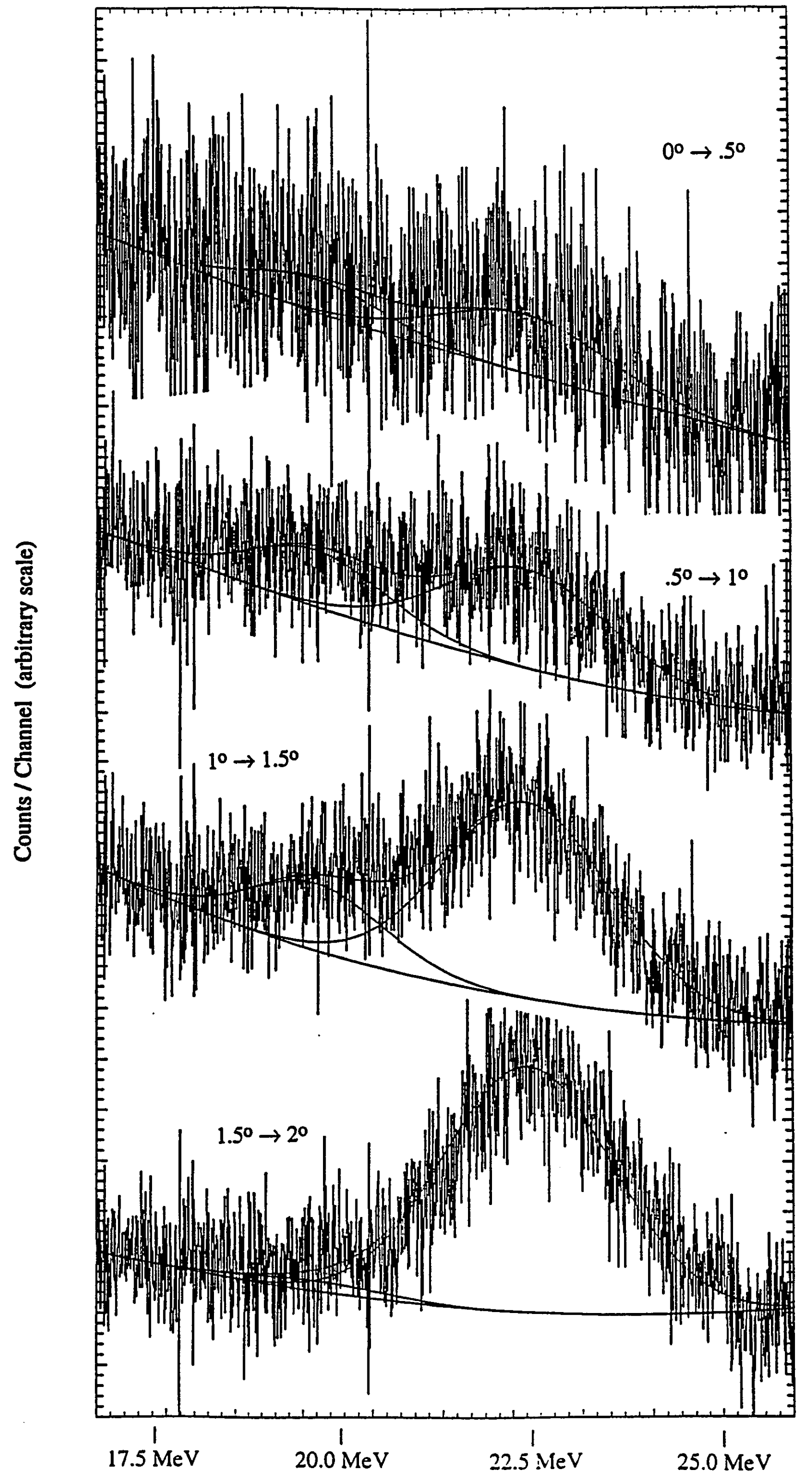

Figure 2. Measured spectra in the region of interest. Data are sorted in four angular bins and fitted by two resonances (solid lines) as explained in the text.

whereby, for 2 nA of beam current, the blank target (empty target frame) runs yielded a count rate of about 190 counts/s as compared to an event rate of about 580 counts/s with the target in place. The live time was typically 80 to 90%. "Cleaning" of the spectra was achieved in part by employing a gate on the TOF from the scintillators.

A broad "bump," comprising the two resonances, is clearly visible above background in our spectra. By using software cuts, it has been possible to split the 2° angular acceptance of the K600 into energy spectra from the 0° to 0.5°, 0.5° to 1.0°, 1.0° to 1.5° and 1.5° to 2.0° angular bins (Fig. 2), thus providing an angular distribution for the two components of the "bump." Indeed, the angular distributions for the two components are strikingly different and in qualitative agreement with the expected angular distributions for the ISGDR and HEOR. In Fig. 3 the measured and calculated angular distributions for both resonanes in ^{208}Pb are compared in the measured angular range. Inelastic scattering of alpha particles near 0° has the advantage that, because of the isoscalar nature of this reaction, only these two giant resonances are expected to be predominantly excited at the excitation energies of interest. In addition, as indicated by the calculations presented in Fig. 3, the cross sections for these resonances are at or near their maximum at these very forward angles.[1]

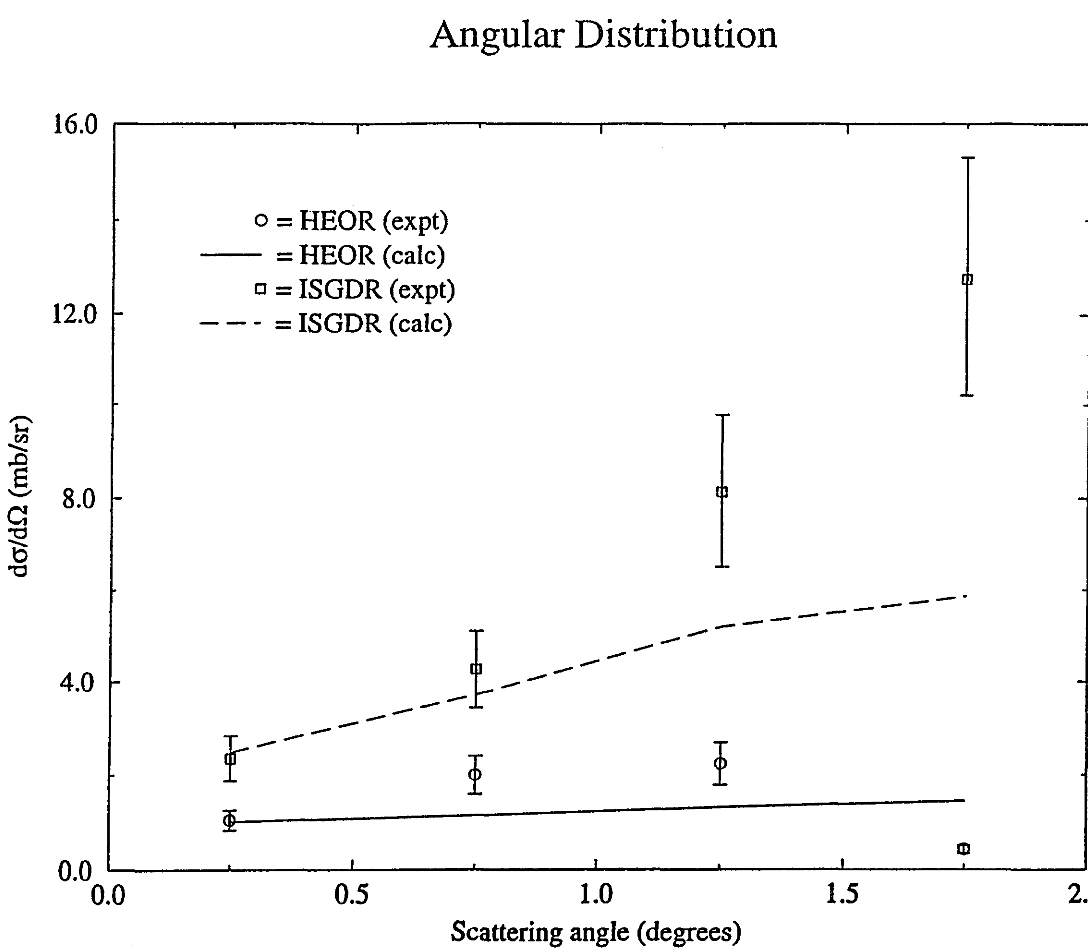

Figure 3. Measured and calculated cross section angular distributions of the ISGDR and the HEOR are compared in this figure.

The DWBA calculations were performed using the program CHUCK3.[5] The optical model parameters used are: V = 155 MeV, r = 1.282 fm, a = 0.677 fm, W = 23.26 MeV, r_w = 1.478 fm, a_w = 0.733 fm and r_c = 1.3 fm. They were adopted from Ref. 6. For the HEOR, the standard collective form factor[7] was used; for the ISGDR, the form factor was taken from Ref. 2.

We also employed the "difference-of-spectra" technique,[8] as described in last year's Annual Report,[1] to extract the parameters of the ISGDR. This technique, previously used to great effect in the investigation of the giant monopole resonance,[8] takes advantage of the roughly flat angular distribution of the HEOR over the 0° to 2° range as compared to that of the ISGDR, which has a monotonically increasing cross section over the same angular range. The spectrum corresponding to the 0° to 1° scattering angle range, when subtracted from the normalized spectrum corresponding to 1° to 2° scattering angle range results in an energy spectrum made up almost entirely of the contribution from the ISGDR. Fig. 4 shows a comparison of the subtracted spectrum (b) versus the spectrum of the full 2° K600 acceptance (a). Our measurements have confirmed the efficacy of this technique in the study of the ISGDR and provided a clear evidence for this resonance in ^{208}Pb. The excitation energies extracted from a two-peak fit to the "bump" – 19.7(5) MeV for the HEOR and 22.4(5) MeV for the ISGDR – are slightly higher (on the average) than previously reported;[9–11] the extracted widths of both the resonances ($\leq$ 3 MeV), on the other hand, are smaller.

Preliminary results from this experiment were presented at the Gull Lake Nuclear Physics Conference on Giant Resonances, Gull Lake, Michigan, August 17-21, 1993.[12]

1. B.F. Davis, *et al.*, IUCF Sci. and Tech. Rep. May 1992 - April 1993, p. 34.
2. M.N. Harakeh, Phys. Lett. **B90**, 13 (1980).
3. A. van der Woude, in *Electric and Magnetic Giant Resonances in Nuclei*, ed. J. Speth (World Scientific, 1991) p. 100.
4. G.P.A. Berg, *et al.*, this report.
5. P.D. Kunz, University of Colorado, (unpublished 1993).
6. D.A. Goldberg, *et al.*, Phys. Rev. C **7**, 1938 (1973).
7. G.R. Satchler, in *Particles and Nuclei* **5**, 105 (1973).
8. S. Brandenburg, *et al.*, Nucl. Phys. **A446**, 29 (1987).
9. H.P. Morsch, *et al.*, Phys. Rev. Lett. **45**, 337 (1980); and Phys. Rev. C **28**, 1947 (1983).
10. C. Djalali, *et al.*, Nucl. Phys. **A380**, 42 (1982).
11. G.S. Adams, *et al.*, Phys. Rev. C **33**, 2054 (1986).
12. B.F. Davis, *et al.*, Nucl. Phys. **A569**, 325c (1994).

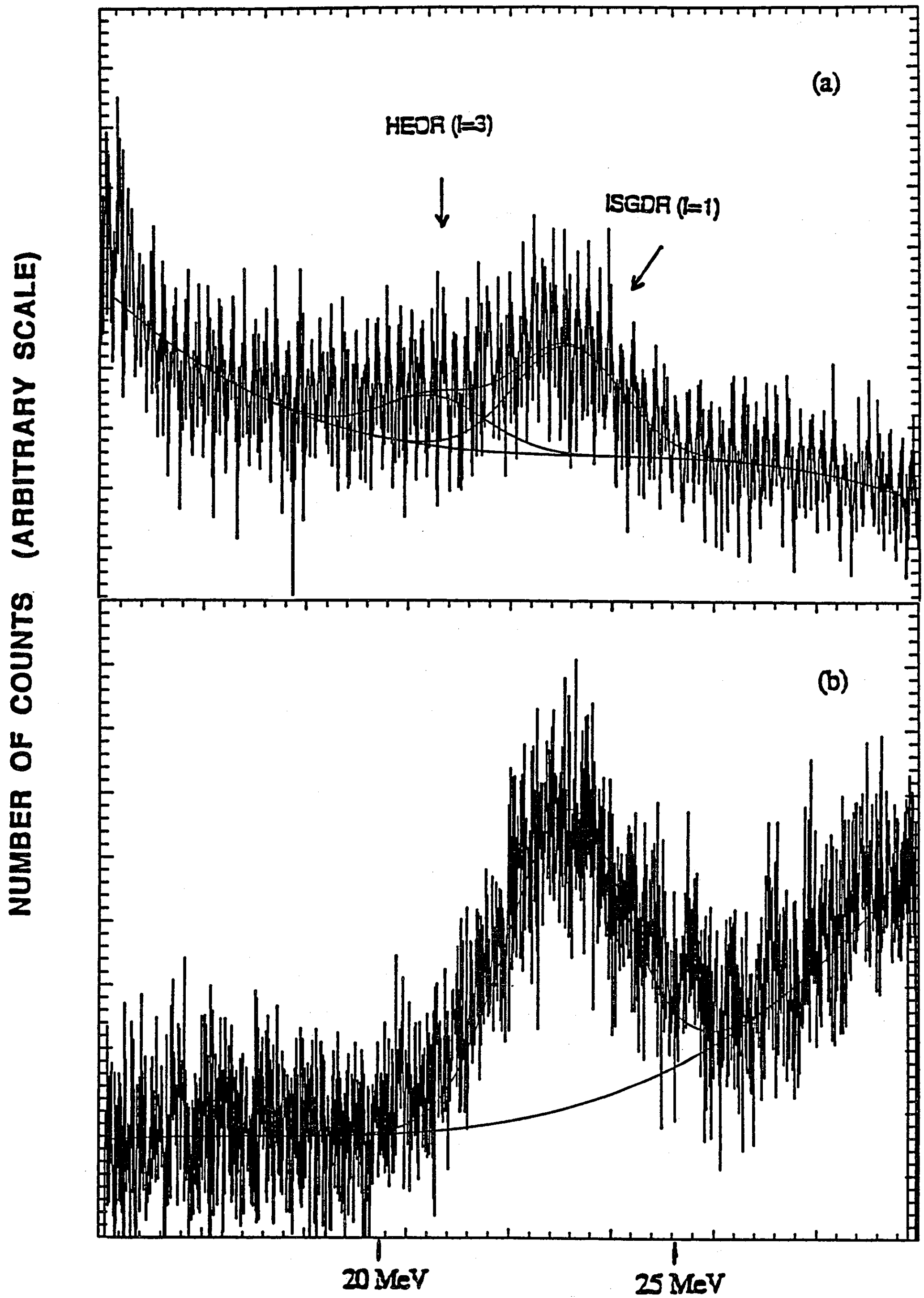

Figure 4. Shown are the spectra (a) measured in the full angular range and the difference spectrum (b) as explained in the text. The ripple of the online spectrum (a) is a detector artifact which was corrected in the other spectra shown in this report.